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To Mr. F.J. Kee
Director of Research

# RETURN AIR PLENUM HEATER

F.G. Pellini and B.G. Woods

In some residential oil furnaces, the presence of various peripheral equipment prohibits the installation of electric heaters in the warm air plenum. More installation flexibility could be provided if the heaters could be installed in the return air plenum. A study was performed in the latter half of 1983 to determine the safety and performance aspects of a return air plenum heater. The results of the tests performed in the laboratory show that a 9 kW heater in the return air plenum operated safely and the only significant effect on the performance was the temperature-time response of the delivered air.

## 1.0 INTRODUCTION

The installation of electric heaters in furnace warm air plenums can be prohibited when other peripheral equipment ('A'-coil, humidifier, etc) is installed in the warm air plenum, and the specified clearances for the heater cannot be met. A dual fuel system could still be provided though if the electric heater could be installed in the return air plenum.

The objective of this study was to determine the magnitude of any potential effects on a heating system during the operation of a 9 kW return air plenum heater. During the latter half of 1983 various manufacturers and specialists were consulted to determine the range of possible effects, and tests were conducted on a prototype in the laboratory.



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The operating safety of plenum heaters installed in warm air plenums of oil furnaces is well controlled by the regulatory bodies. Therefore, the main emphasis of this study was to look at situations unique to similar heaters installed in the return air plenums of oil furnaces.

The first step was to establish that a heating system can operate safely with a return air plenum heater. The second step was to determine the magnitude of the factors affecting the feasibility of a return air plenum heater.

The general configuration for a heating system with a return air plenum heater is shown in Figure 1.

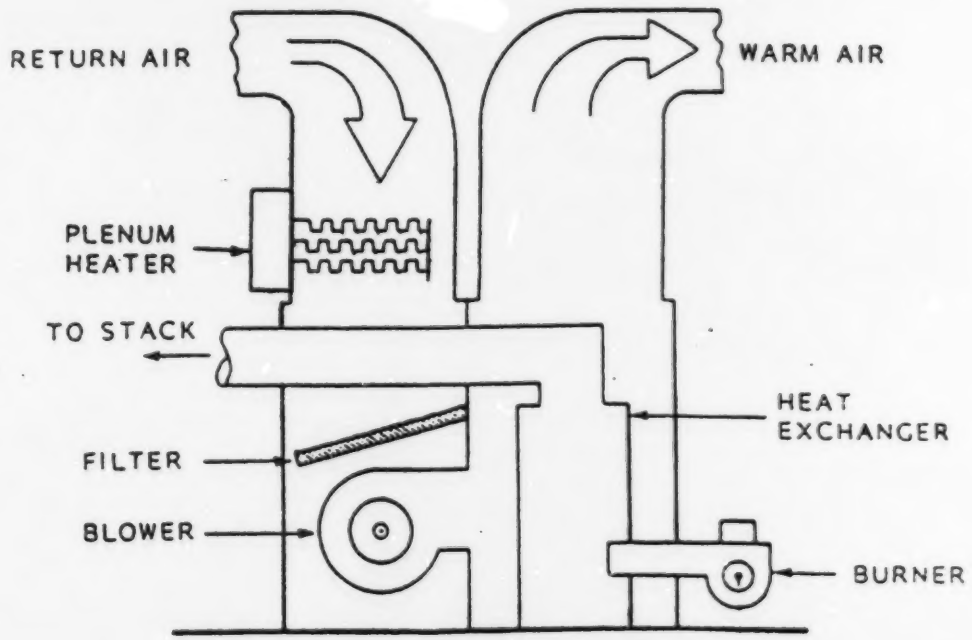



FIGURE 1

GENERAL CONFIGURATION FOR AN OIL FURNACE WITH A RETURN AIR PLENUM HEATER

It can be seen that the operation of a return air plenum heater may raise some concerns regarding the reliability and performance of a heating system. The reliability, or safety aspects were identified as:

1. Blower motor overheating.

2. Wire insulation overheating.

3. Excessive surface temperatures.

4. Excessive air filter temperatures.

The system performance aspects were identified as:

1. Blower performance at higher temperatures.

2. Air temperature response in the warm air plenum (due to heat storage in the furnace heat exchanger).

3. Flue duct heat losses.

4. Particulate accumulation on the heater elements due to the location of the heater upstream of the air filter.

Further descriptions of these problems are given in the appendix, as well as the results of the tests performed to address the concerns.

## 2.0 SUMMARY OF RESULTS

The results from the laboratory tests indicate that during the operation of the 9 kW return air plenum heater:

1. The blower motor temperature did not exceed acceptable operating values (Section 1.1 in appendix).

2. The wires in the furnace casing did not overheat (Section 1.2 in appendix).

3. The temperatures of the exposed surfaces on the furnace or plenums were not adversely affected (Section 1.3 in appendix).

4. The air filter did not overheat (Section 1.4 in appendix).

5. The performance of the blower did not change significantly (Section 2.1 in appendix).

6. There was a detectable delay in the heat available from a heater in the return air plenum compared to a heater in the warm air plenum (Section 2.2 in appendix).

7. The portion of the heater's output that was lost to the flue duct represented an insignificant amount of the heat supplied by the heater (Section 2.3 in appendix).

8. There was no accumulation of particles on the heater elements noticed from the lab tests (Section 2.4 in appendix).

## 3.0 CONCLUSION

The return air plenum heater has the potential to become a viable alternative to warm air plenum heaters for dual energy systems. Field trials are needed though, to confirm the long term performance of return air plenum heaters.

Approved:

A.F. Baljet
Manager
Electrical Research Dept

Submitted:

F.G. Pellini
Engineer
Utilization Section

B.G. Woods
Engineer
Utilization Section

FGP/BGW:km/lg

## REFERENCES


1. CSA Electrical Bulletin No 1302, Requirements for Plenum-Mounted Add-On Electric Heaters for Field-Installed Forced Warm Air Oil Furnaces.

2. CSA Standard C22.2 No 100, Motors and Generators.

3. CSA Standard B140.4, Oil-Fired Warm Air Furnaces.

4. ASHRAE Handbook, 1981, Fundamentals Volume, Chapter 8 - Physiological Principles, Comfort, and Health.

## APPENDIX

## DESCRIPTION OF SITUATIONS CHECKED AND RESULTS FROM LAB TESTS

### 1. Reliability Aspects

### 1.1 Blower Motor Overheating

A forced air heating system with a return air plenum heater will have heated air passing over the furnace blower motor and therefore the possibility of motor overheating exists.

The maximum allowable motor winding temperature, as specified by CSA/1/ for Class A motors at all wattage ratings, is 100°C when measured with a thermocouple. In preliminary tests, the motor winding temperature was found to be higher than the motor casing temperature by 11°C. Therefore, the winding temperature during the tests, was determined by adding 11°C to the casing temperatures.

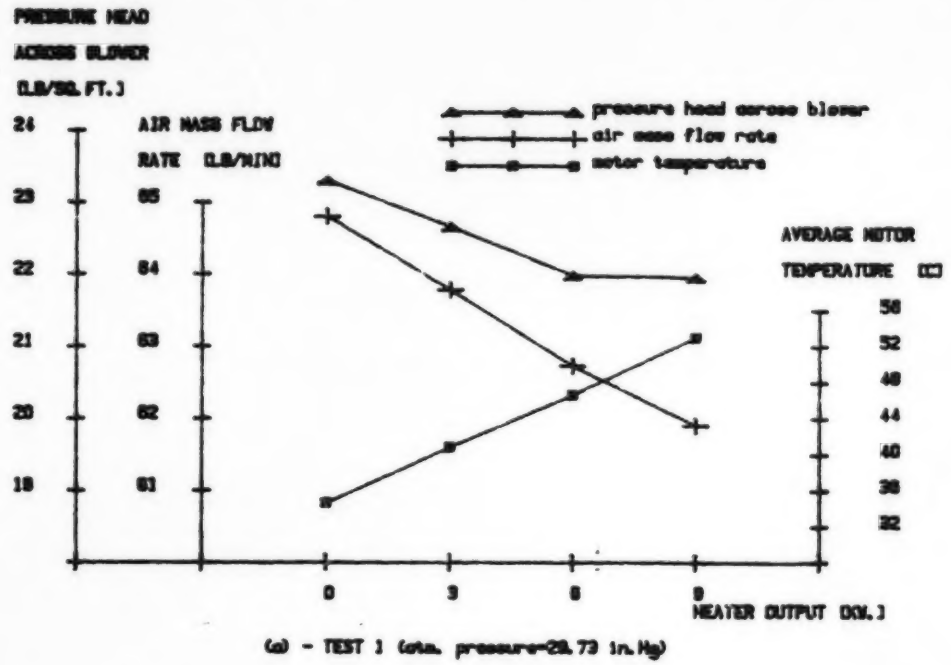
The CSA motor winding temperature limit was the main criteria for motor temperature acceptability, but another concern was that the warmer air may cause additional heating within the motor (ie, changes in eddy current or hysteresis losses). Additional motor heating would be recognizable by a non-linear relation between the motor temperature and the heater output.

#### Results

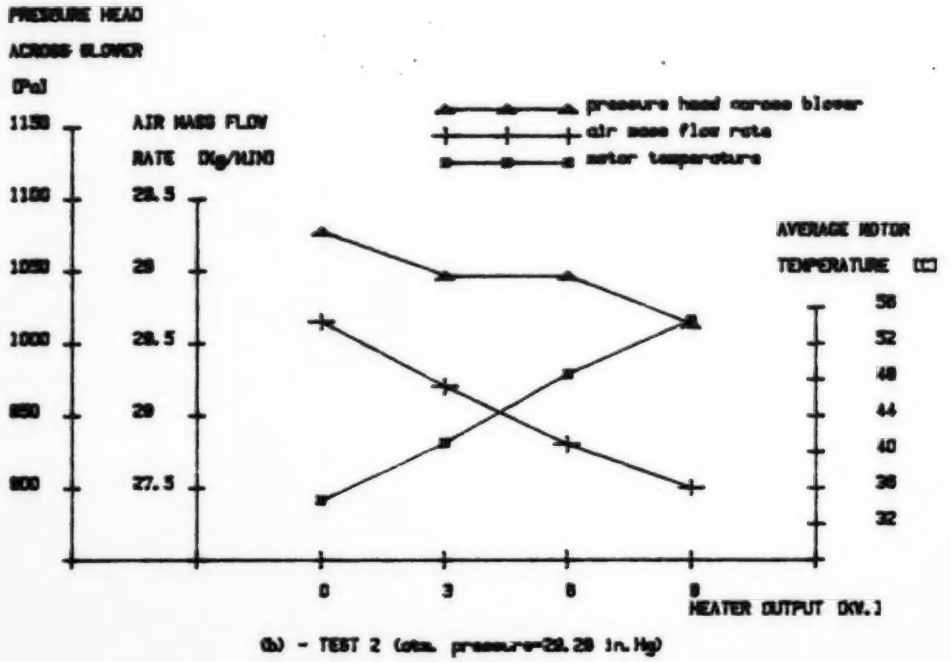
To determine the magnitude of the motor temperatures, two thermocouples were attached to the blower motor casing. The maximum motor casing temperature during any of the tests was found to be approximately 56.8°C (see Table I). The winding temperature was therefore approximately 68°C (using the temperature difference mentioned above), which is within the limit specified by CSA.

The motor temperature versus heater output relationship is close to linear for both tests (see Figure 2). Therefore, the higher air temperatures do not appear to aggravate any internal heating (note; the differences in the results shown in Figure 2 are mainly due to the different atmospheric conditions during the two tests).

Therefore, the blower motor should operate safely in conjunction with a 9 kW return air plenum heater.




(a) - TEST 1 (atm. pressure=28.73 in.Hg)




(b) - TEST 2 (atm. pressure=28.28 in.Hg)

FIGURE 2 - MOTOR PERFORMANCE RESPONSE

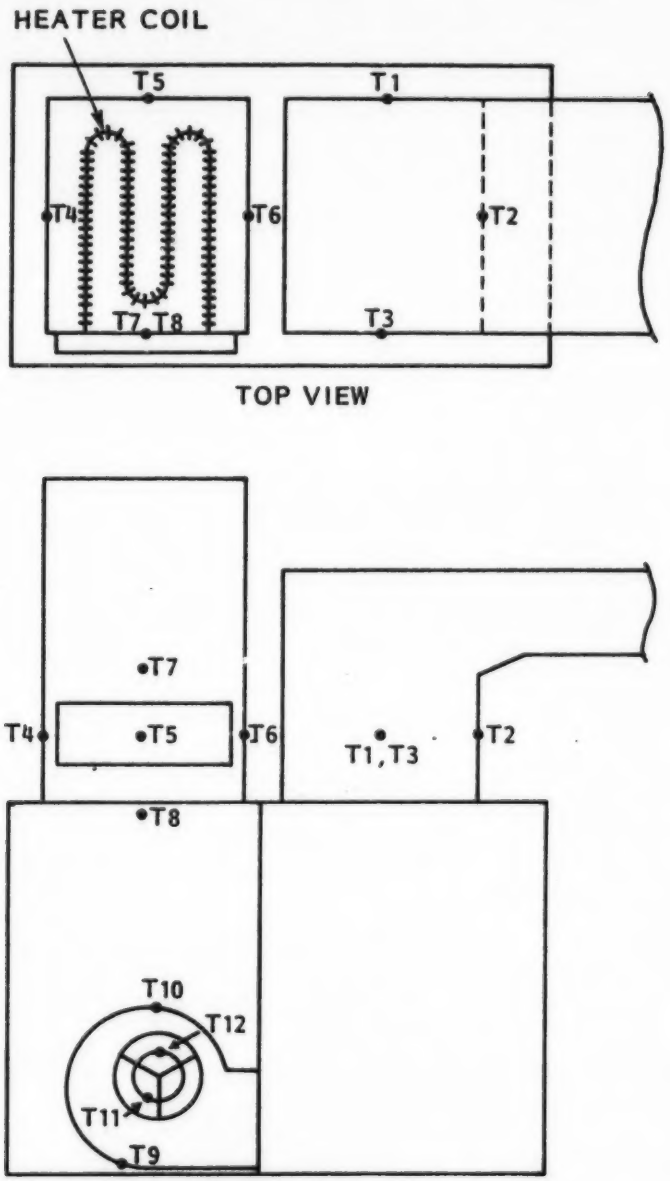



FIGURE 3
THERMOCOUPLE LOCATIONS
ON TEST APPARATUS

TABLE I

PLENUM SURFACE AND BLOWER MAXIMUM TEMPERATURES

| Thermocouple Location | Temperature Location (see Figure 3) | Maximum Temperature |
|---|---|---|
| Warm Air Plenum Surface | T1 | 36.3°C |
| Warm Air Plenum Surface | T2 | 38.2°C |
| Warm Air Plenum Surface | T3 | 38.8°C |
| Return Air Plenum Surface | T4 | 32.8°C |
| Return Air Plenum Surface | T5 | 25.4°C |
| Return Air Plenum Surface | T6 | 29.9°C |
| Return Air Plenum Surface | T7 | 30.4°C |
| Return Air Plenum Surface | T8 | 30.0°C |
| Blower Casing | T9 | 43.7°C |
| Blower Casing | T10 | 44.9°C |
| Motor Casing | T11 | 52.9°C |
| Motor Casing | T12 | 56.8°C |

## 1.2 Wire Insulation Overheating

Various electrical conductors are often located in the section of the furnace which is upstream of the fan. During normal furnace operation, unheated air passes over these conductors. With a return air plenum heater, these conductors may be exposed to higher air temperatures and therefore there was a concern about the conductor insulation.

The main criteria for the maximum temperature of conductor insulation was the CSA/1/ limit of 90°C (for most types of wire insulation used).

In preliminary tests, it was found that the maximum temperature of an energized conductor, in the furnace, exceeds the air temperature by approximately 1°C. Since the conductors are usually away from the main air stream (ie, attached to the base of the furnace, below the fan) the temperature of the air around the conductors is usually less than the average air temperature. The maximum air temperature plus 1°C was therefore used as a conservative estimate of the maximum insulation temperature.

Results

In the various test runs, the maximum air temperature immediately downstream of the heater was found to be 51.3°C. Assuming a gaussian distribution of the results from all the tests run, and using the worst case data (ie highest average temperature and largest deviation), the maximum expected air temperature at a 99% confidence level is 55.5°C. The maximum conductor insulation temperature that can be expected is therefore approximately 56.5°C (including self heating effects as stated above).

The maximum conductor insulation temperatures that can be expected are much lower than the maximum temperature limit for conductor insulation. Therefore, the operation of a 9 kW return air plenum heater should not cause conductor insulation overheating.

## 1.3 Surface Temperatures

It was not expected that the furnace surface temperatures during the return air plenum heater operation would be higher than the surface temperatures during normal furnace burner operation, but it was necessary to confirm this by actual meaurement.

The maximum allowable temperatures for exposed surfaces of furnace, plenum or ductwork is specified by CSA/1/ as 90°C.

Results

To monitor the surface temperatures during heater operation, thermocouples were placed at certain locations on the furnace shell and both plenums (see Figure 3 for the location of individual thermocouples). The maximum temperatures recorded by these thermocouples during the tests are shown in Table 1.

The maximum observed temperature on any surface during the tests was 38.8°C which is much lower than the specified maximum allowable temperature. Therefore, the surface temperatures are not adversely affected by the operation of a 9 kW return air plenum heater.

## 1.4 Air Filter Temperature

On furnaces with a return air plenum heater, the air is heated before it enters the furnace. The air filter is therefore warmer with a return air plenum heater than it is during the operation of the oil burner or a warm air plenum heater.

The CSA standard for Oil-Fired Warm Air Furnaces/3/ states that the location of the air filter should be such that the maximum filter temperature does not exceed the inlet temperature by more than 50°C (90°F).

Results

The air filter temperature was measured with a thermocouple grid on the side of the filter exposed to the plenum heater. To simulate the "worst case" conditions, the air filter was placed approximately 2.5 cm below the heater elements (compared to a clearance of at least 25 cm for typical field installations).

The maximum temperature at the air filter was observed to be 57.5°C, which exceeded the inlet air temperature by 31.5°C.

The 9 kW return air plenum heater therefore did not cause the air filter to overheat, even with the worst case situation simulated in the lab tests.

## 2. System Performance

### 2.1 Blower Motor Performance

It has been established that passing heated air across the blower motor does not cause the motor to overheat (see Section 1.1). However, it was expected that heated air would affect the performance of the blower.

To evaluate the motor performance during the tests, the change in the pressure head across the blower and the air mass flow rate were monitored as the three heater elements were energized successively (pressure head is the difference in total pressure between the blower input and output and is representative of the energy supplied by the blower).

Results

The effect on the blower performance parameters, as observed in the lab tests, are shown in Figure 2. The total drop in pressure head after the heater elements were turned on was approximately 6%, and the drop in the air mass flow rate was approximately 4.5%. Therefore, the operation of a return air plenum heater results in a very slight decrease in blower performance, but not enough to prohibit the use of return air plenum heaters. Also, the decrease in blower performance has a small but positive effect on the heating system comfort as it results in a slightly higher air temperature rise (there have been some complaints that the air heated by smaller capacity plenum heaters is not warm enough).

## 2.2 Air Temperature Response

When a plenum heater in the warm air plenum (conventional location) is started or shut off, the rate at which the temperature of the supplied air changes depends mainly upon the rate at which the heater temperature changes. With a return air plenum heater, the location of the furnace heat exchanger (downstream of the electric heater) causes the response of the air temperature to be slower than the response with the plenum heater in the warm air plenum.

### Results

In order to determine the speed of the air temperature response with a return air plenum heater, tests were run on a 27 kW (96 000 BTUH) rated oil furnace. As can be seen in Figure 4, the air in the warm air plenum took just over 2 minutes (point A on Figure 4) to reach 63% of the maximum change in air temperature (63% is the portion representative of one time constant in an exponential distribution) and seven minutes to reach 90% of the maximum air temperature change (Point B on Figure 4). In comparison, the response of a furnace with a warm air plenum heater would be essentially the same as the response of the heater itself. The response of the heater is represented in Figure 4 by the air temperature immediately downstream of the heater. Therefore, a warm air plenum heater would take 1.5 minutes to reach 63% of the maximum air temperature change (point C on Figure 4) and 2.5 minutes to reach 90% of the maximum temperature change (point D on Figure 4).

The slower air temperature response was found to be the most obvious affect of the operation of a return air plenum heater. Although there is some additional delay on the delivery of the available heat, the slower response may increase the system comfort by reducing the rate of temperature change. (In studies reported by ASHRAE/4/, thermal comfort was found to decrease as the rate of temperature change increased). In any case, the total delay on the delivery of heat to the register outlets of the heating system is not likely to be significantly affected by the return air location of the heater.

## 2.3 Flue Duct Heat Loss

During the operation of a warm air plenum heater, the air is heated after it leaves the furnace and therefore the majority of heat losses in the furnace are avoided. During the operation of a return air plenum heater, the air is heated before it enters the furnace. Therefore, some of the heat is radiated from the furnace shell, some is stored in the furnace heat exchanger, and some is lost up the flue duct.

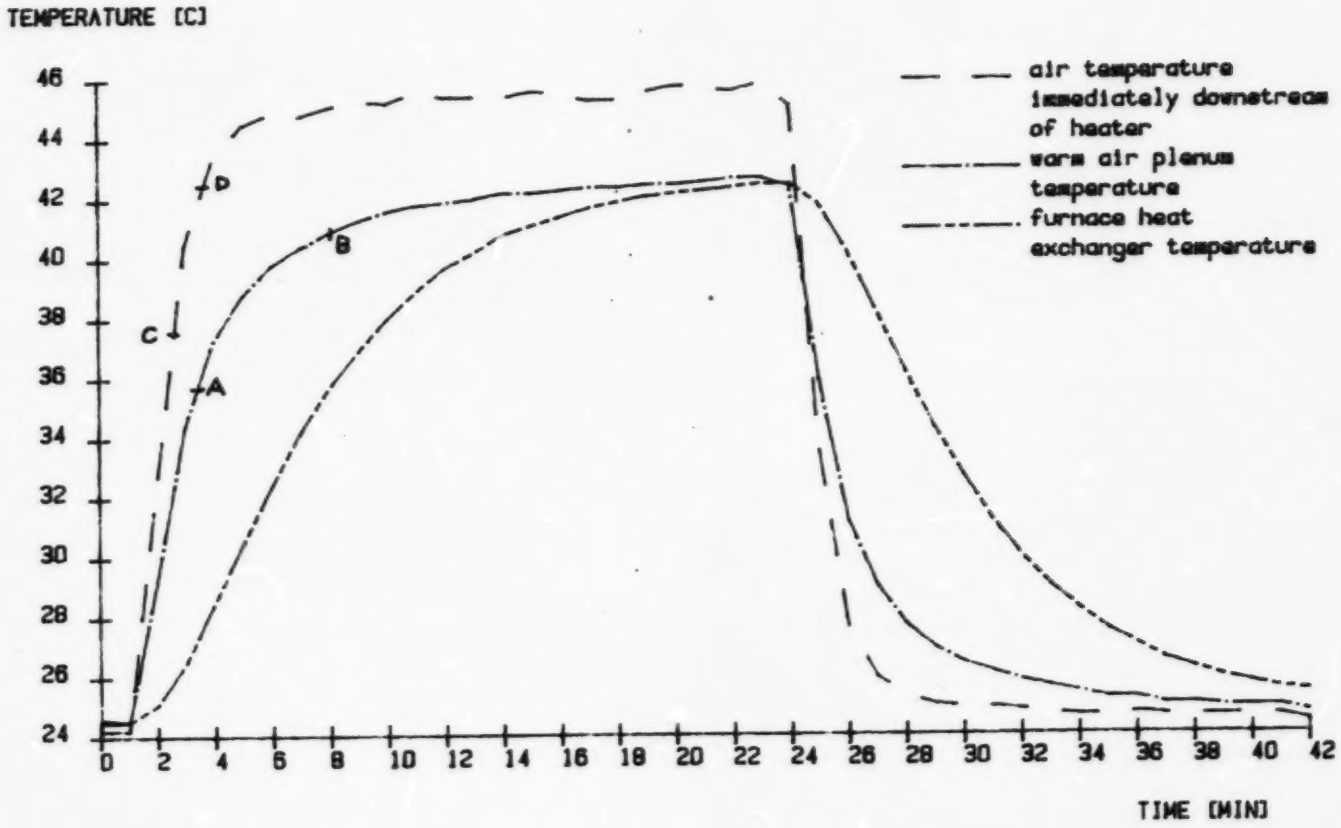



FIGURE 4 - TRANSIENT TEMPERATURE RESPONSE

To determine the portion of the plenum heater's output that is lost to the flue duct in the lab tests, the temperature and flow rate of the air in the flue duct were monitored before and during heater operation. In making this measurement, it was found that the natural air flow up the flue duct, induced by venting the flue to outdoors, was too variable to permit the necessary steady state temperature and flow readings to be made. Consequently, a constant air flow of 12 L/s (25 cfm) which is representative of the natural air flow, was induced in the flue for the purpose of conducting this measurement.

Results

The flue duct losses were found to be approximately 0.3% of the heater output when the flue was vented as described above. From measurements made under uncontrolled draft conditions, it is estimated that the upper bound on these losses is one to two per cent of the heater output.

Although heat losses are not desirable, the magnitude of the flue duct losses observed should not be considered restrictive for return air plenum heaters.

2.4.1 Particulate Accumulation on Heater Elements

The location of the air filter in the furnace is such that during periods when a return air plenum heater is not used and the blower is, there could be varying degrees of particulate accumulation on the heater elements. When the heater is turned on, the odours caused by any burning of this particulate might cause some concern. Although this effect was not noticed during the tests, the air filter could be moved just upstream of the heater if this turned out to be an annoyance.